

INPUT AND OUTPUT IN THE SYSTEM OF THERMOREGULATION  
DURING REST AND EXERCISE

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# INPUT AND OUTPUT IN THE SYSTEM OF THERMOREGULATION DURING REST AND EXERCISE

## III. The Role of Water Balance in Thermoregulation During Rest and Exercise

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ABSTRACT. Sweat rate  $G_{sw}$  and heat conductance  $k$  remain nearly constant despite a steady increase in core temperature during experiments in a hot environment. The water loss during the experiments must be taken in account in input-output correlations. Water loss during the experiments was replaced. The correlation equations described in the 2nd part of this paper, hold without a correction factor. Esophageal temperature during exercise in these experiments was steady in the first  $\frac{1}{2}$  hour. After 2 hours esophageal temperature in a warm climate is markedly lower than in the control experiments.

As indicated in our Part II, the sweat rate,  $G_{sw}$ , and the internal heat conductance,  $k$ , also depend on the water loss suffered by the subject, and this is in addition to the thermal input (core temperature  $T_{oe}$  and skin temperature  $\bar{T}_s$ ). This finding is in accordance with the literature (Hertzman and Ferguson, 1960; Senay and Christensen, 1965b; Senay and v. Beaumont, 1969). We introduced a correction factor for the water loss in the correlation analyses of Part II. We intend to recheck the justification for this correction factor in this article by fluid replacement during the experiments.

### Methods

The arrangement of the experiment, the course of experiment, and the calculations resemble the procedure described in the previous two parts, with the following differences:

1. only experimental conditions with sweat rates  $G_{sw} > 5$  g/min were investigated;
2. during the experiments the subject had to place a 20 g weight on the scale for each 150 g of weight loss. He received an infusion of 130 ml of fluid through a stomach probe (0.35% NaCl solution; in some experiments a sweat

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\* Numbers in the margin indicate pagination in the foreign text.

substitute solution of the following composition, as available on the market:  
NaCl 0.23%, KCl 0.03%,  $\text{NaHCO}_3$  0.175%,  $\text{CaCO}_3$  0.02%, MgO 0.01%, citric acid 0.31%,  
glucose 0.4%; also thiamine mononitrate 1.2 mg/l, riboflavin-5-phosphate 2.5 mg/l,  
nicotinamide 16 mg/l, ascorbic acid 100 mg/l).

The infusion was triggered by the subject by pressing a button. This activated an electric pump and took but 30 sec. The solution was warmed to the core temperature expected in the experiments. The first infusion was administered immediately before the start of the experiment;

3. sweat was collected from about a  $3 \text{ cm}^2$  skin area of the chest throughout the experiments. A small vessel with histoacryl-N (Braun, Melsungen) was adhered to the skin for this purpose. The sweat was examined for Na content by flame photometry;

4. in some experiments the hematocrit value was determined before and after the start of the experiment from freely flowing venous blood (without stasis);

5. all measurements in Part I, as well as the values in this series, were used to calculate  $G_{\text{sw}}^+$  and  $K^+$  (See Part II).  $b = 0$  was substituted for the latter in Eqs. (5) and (6) in Part II.

The gastric content was removed by suction, and its volume was determined, immediately before the start and after the end of some experiments. The subjects were fasting in these cases. About 20 to 140 ml of juice was removed from the stomach by suction at the end of the experiments.

## Results

1. Figure 1 shows the core temperature as a function of ambient temperature in experiments with and without fluid replacement. The values in the experiments with fluid replacement were below the comparative values. The basic shape of the curve remains, even though the zone of indifference is almost horizontal, and the subsequent steep slope of the curve is much flatter in a very hot environment. The temporal behavior of the core temperature is to reach constant, final value within the first half hour in all experimental conditions examined.

2. Fluid replacement has no measurable effect on skin temperature.

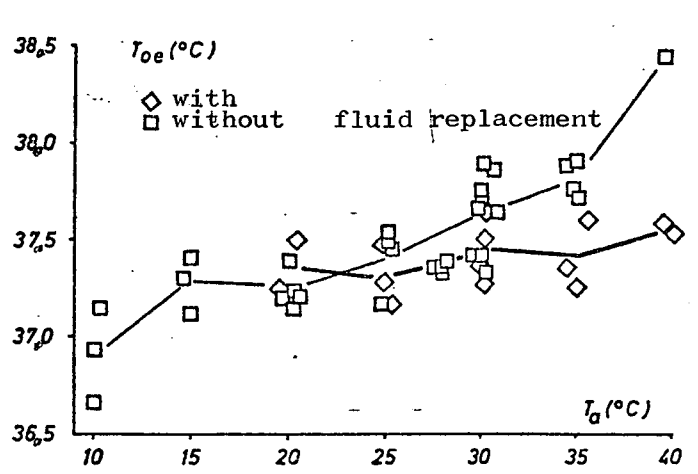


Figure 1. Deep esophageal temperature  $T_{oe}$  versus ambient temperature  $T_a$ . Work load 900 kpm/min. Data taken 2 hours after beginning of exercise. Subject J. S. Thick line: fluid replacement; thin line: no fluid replacement.

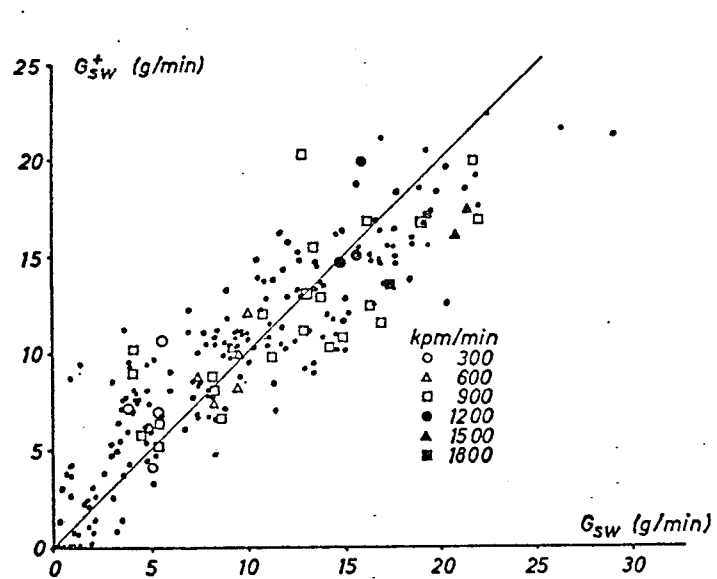


Figure 2. Calculated sweat rate  $G_{sw}^+$  plotted against the experimental values  $G_{sw}$ . Points: fluid replacement (see Figure 1 of the foregoing communication); other symbols: no fluid replacement. Subjects: H. R. and J. S.

TABLE I

Subject	Output	$a_0 \pm s_0$	$a_1 \pm s_1$	$a_2 \pm s_2$	$a_3 \pm s_3$	$a_4 \pm s_4$	n	r	s
J. S.	$G_{sw}^+$ (g/min)	I $-469.4 \pm 3.4$	$12.16 \pm 0.08$	$0.86 \pm 0.01$			137	0.92	$\pm 2.6$
		II $-567.0 \pm 5.6$	$14.70 \pm 0.15$	$0.94 \pm 0.01$			43	0.95	$\pm 2.1$
	$k^+$ (kcal/°C min)	I $-17.53 \pm 0.83$	$0.46 \pm 0.02$	$0.22 \pm 0.07$	$-0.014 \pm 0.003$	$0.00028 \pm 0.00004$	131	0.86	$\pm 0.23$
		II $-19.50 \pm 2.12$	$0.53 \pm 0.03$	$0.14 \pm 0.20$	$-0.011 \pm 0.007$	$0.00035 \pm 0.00009$	40	0.93	$\pm 0.22$
H. R.	$G_{sw}^+$ (g/min)	I $-380.6 \pm 1.5$	$9.74 \pm 0.13$	$0.84 \pm 0.02$			72	0.87	$\pm 2.9$
		II $-460.9 \pm 8.9$	$11.82 \pm 0.21$	$0.92 \pm 0.02$			27	0.93	$\pm 2.0$
	$k^+$ (kcal/°C min)	I $-22.61 \pm 1.66$	$0.69 \pm 0.02$	$-0.15 \pm 0.15$	$-0.002 \pm 0.005$	$0.00016 \pm 0.00006$	76	0.89	$\pm 0.28$
		II $-23.68 \pm 3.27$	$0.69 \pm 0.04$	$-0.07 \pm 0.33$	$-0.004 \pm 0.012$	$0.00018 \pm 0.00001$	30	0.94	$\pm 0.21$

$$\text{Output} = (a_0 + a_1 T_{oe} + a_2 T^2 + a_3 T^3 + a_4 T^3) (1 - 0.0001 \int_0^t G_{sw} dt). \quad I = \text{Calculation}$$

from separate values, II = Calculation from the mean values of each experimental condition.  
n = Number of experiments, resp. experimental conditions ( $G_{sw} \geq 1$  g/min,  $k \geq 0.5$  kcal/°C min).  
r = Multiple correlation coefficient. s = Standard deviation of theoretical and experimental values.  $s_i$  = Standard deviation of the coefficients.

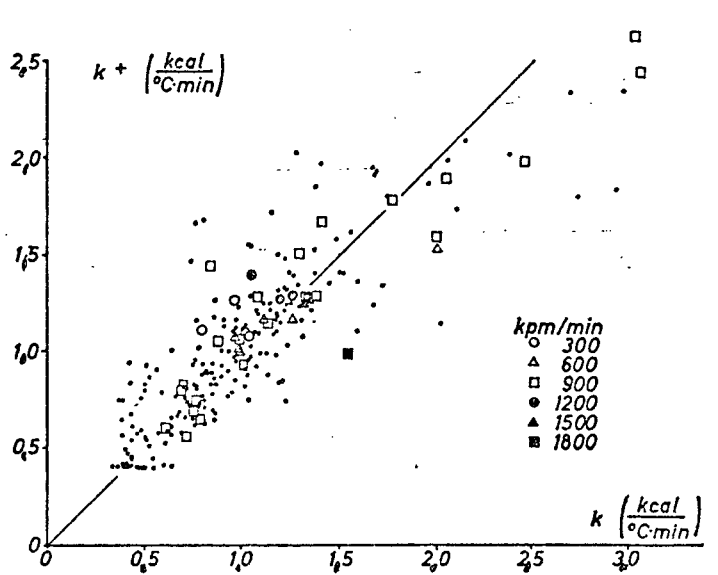


Figure 3. Calculated heat conductance  $k^+$  plotted against experimental values  $k$ . Symbols see Figure 2. Subjects H. R. and J. S.

3. The sweat rate, and the internal heat conductance, are almost as high at the end of the experiment in the case of fluid replacement as in the experiments without fluid replacement, under otherwise similar experimental conditions.

4. The correlation analyses made using Eqs. (5) and (6) of Part II produce almost the same values as in Part II. (see Table 1). Values for the experiments with fluid replacement show no systematic deviations when compared with values without fluid replacement (Figures 2 and 3).

5. The sodium content of sweat is a function of the sweat rate. It is independent of the fluid supply within the limits of error for the method.

6. All findings are the same for experiments with 0.35% NaCl solution used for fluid replacement, or with commercial solutions used for sweat replacement.

### Discussion

We administered 130 ml of fluid for each 150 g weight loss by the subjects.

This value results from the water loss with sweat and with respiration, as opposed to the water gain from oxidation water and water released by glycogen mobilization. The water gain can only be estimated. It is about 1.7 g of water per liter of  $O_2$  /191 consumption (See Saltin, 1964; Olsson and Saltin, 1970); about 3.25 g/min at 900 kpm/min. At this load, the subject loses about 0.4 g of his weight per minute because of the weight difference between  $O_2$  intake and  $CO_2$  output. A measured weight loss of 25 g/min therefore means a water loss of 21.35 g so the 150 g weight loss must be replaced by 128 ml of solution. The relative error is larger in the case of lower sweat rates and the subject receives more water than he loses. No fluid replacement would be required for example, in the case of a load of 900 kpm/min and 3.25 g/min weight loss. Actually, the subject receives 2 x 130 ml during the 2 hours of experimentation. We ignored this error. And consideration must be given to the fact that the solution is not completely absorbed during the experimental period. In contrast to Costill et al. (1970), we recovered a relatively small amount of fluid from the subject's stomach at the end of the experiments, but unanswered is how much fluid remained in the intestines.

Our findings show unequivocally the influence of water loss on sweat rate and internal heat conductance. Both magnitudes increase more intensively when the lost fluid is replaced in case of identical thermal input. Accordingly, the core temperature rises less sharply, and dependence on climate is almost indiscernible within the zone of indifference. According to Senay (1970), the concentration of plasma proteins, the osmolarity, and the hematocrit value increase during progressive dehydration. But the changes are not so great that our findings can be explained by direct circulatory affects of changed blood viscosity. Above all, the hematocrit value remains in the range in which viscosity as a function of hematocrit changes but slightly (Whittaker and Winton, 1933). Informative measurements of hematocrit value showed no changes exceeding the limits of error for the method, even though no fluid was supplied, in our experiments. The reason for our findings probably is the result of the altered water and mineral balance. Here, central action on the temperature regulating centers is the most probable, because perspiration, as well as the cutaneous blood flow, are reduced by dehydration for identical thermal input. (Compare Hertzman and Ferguson, 1960; Senay and

Christensen, 1965a; Senay and Beaumont, 1969). The question remains open whether the increased osmolarity produces a shift in the debt value through central osmoreceptors, or directly through neurons that are effective thermostats (Senay and Christensen, 1965c), or whether the sensitivity of the centers is diminished along this same path, as was established by Dantas (1939) and Senay (1969) for <sup>192</sup> the regulation of respiration in case of dehydration. Our findings do not permit an equivocal decision as to these two alternatives.

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